Beamforming measurements

Markus Lörner, Rohde & Schwarz

INTRODUCTION

Beamforming using phased array antennas is a common technology in the aerospace & defense industry for radar, satellite communication and further applications. With the next big step in mobile communication, 5G NR (5G New Radio) will introduce new RF techniques, higher frequencies and wider signal bandwidths. Multi-user MIMO and beamforming will become an essential part especially for mmWave links in the 24 to 28 and 39 GHz range. This will drive the need of phased array antennas as the common antenna form for beamforming and beam-forming chipsets into new dimensions. As some sort of beamforming shall be included even in user equipment, integration, size and cost reduction for beam forming components and antennas will be mandatory.

WHY BEAMFORMING

Beamforming helps in many ways. Beamforming condenses the RF power transmitted from an antenna system into a certain given direction. In contrast to a single element antenna, the transmitted RF power is pointed to a single target. The higher the number of antenna elements, the tighter the beam gets.

Typical RF transmissions are in broadcast mode and point to point or multipoint. In the latter two cases, all energy that is not going towards the receiver or target is wasted power based on the original transmission purpose. Even worse, the signal power not going towards the targeted receiver may be interference to other users.

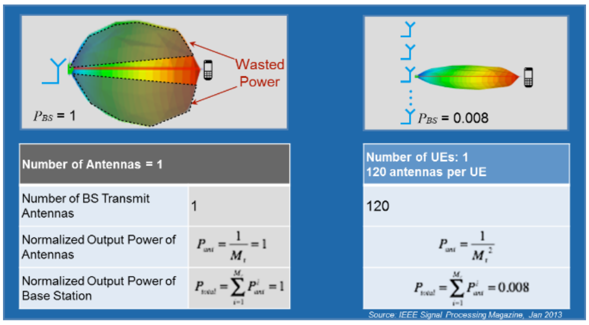

Fig. 1: Number of antenna elements vs directivity

In the example in figure 1, it shows that with 120 antenna elements, less than 1 % of RF power needs to be transmitted to get the same amount of RF level to a receiver compared to a traditional omnidirectional antenna. This becomes very important the higher the RF frequency is as free field attenuation increases as well. In 5G NR mmWave applications, the link budget gets an important topic, which requires special attention to ensure a stable link. Adding more antennas to get the signal beam compact helps to overcome the high free field attenuation.

Sophisticated radar systems allow tracking of multiple targets at the same time using multiple beams simultaneously. As beamforming works for the receive path in the same way as for the transmitter side, these radar systems can distinguish from which direction a signal comes from. Adding the ability to send multiple beams in different directions, the radar can track multiple targets at the same time. The same techniques helps for point to multipoint in mobile wireless applications. One base station can support multiple users at the same time. Having enough separation between the users relative to the beam width, same resources over frequency time and code can be reused. This enables an improved efficiency of the highly precious resource frequency band and allows covering more users at the same time.

BEAMFORMING PRINCIPLES

Beamforming makes use of an overlay of signals trans-mitted from multiple antennas. The signal per antenna is conditioned thus the overlay of the radiated RF fields form a beam in the far field of the antenna structure.

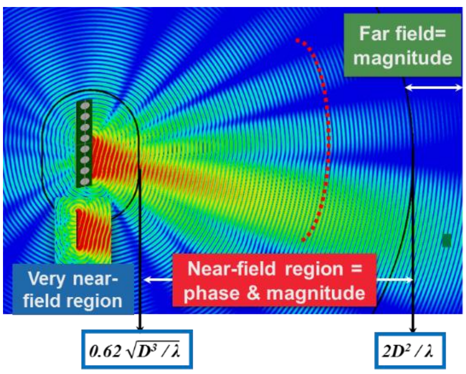

Fig. 2: Electromagnetic fields from an antenna array of eight circular microstrip antenna patches

The common antenna structure for beamforming is the phased array antenna. The far field distance is relative to the RF frequency and the dimension of the antenna. In order to form a proper beamforming signal, each antenna element transmits a modified signal in phase and amplitude. The phase adjustment per antenna elements steers the signal in a certain angle, the level control minimizes the unwanted side lobes.

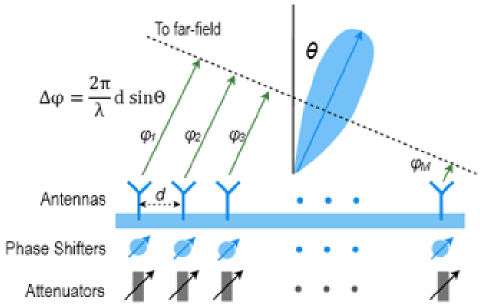

Fig. 3: Beam forming antenna

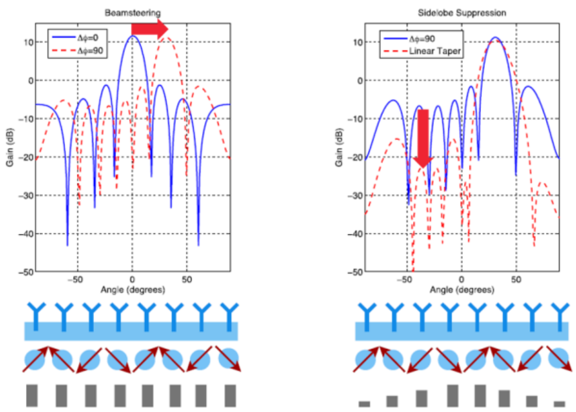

Fig. 4: Influence of phase shift and weighting

To create the different beam forming signals for each antenna, there are two basic concepts: analog and digital beam forming. In analog beamforming, the RF signal is split to go to many antenna elements. The beam forming is done through discrete RF phase shifters and attenuators. This concept is compact and cost efficient as only one RF frontend is needed. For different beams, the structure needs to be duplicated.

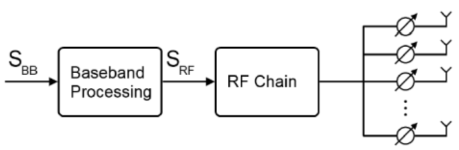

Fig. 5: Analog beamforming concept

Digital beamforming on the other side applies the phase and level variation for the antennas in the digital domain. Thus, every antenna element needs its own RF frontend. The big benefit in this more complex setup is the flexibility. Digitally, multiple beams can be generated and added on top of each other and supplied to the different antenna elements.

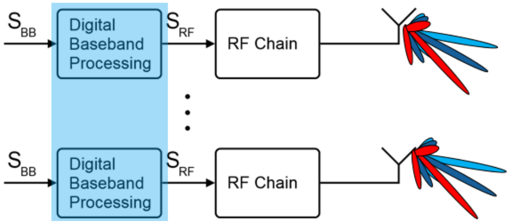

Fig. 6: Digital beamforming concept

In a real world application, the system designers want to benefit from both worlds. They need the flexibility and multiuser support of the digital system. In addition, they need a high amount of antenna elements to form a pointed and narrow beam to help with the link budget. To control costs, size and power consumption, the winning concept will be a hybrid beamforming concept. It will offer multiuser support from the digital part and use analog beamforming on top to increase the number of antenna elements getting the beam more directed.

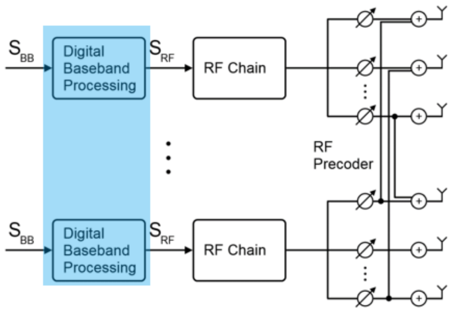

Fig. 7: Hybrid beam forming concept

No matter if the beamforming is done digitally or analog, the control is digital. To get narrow pointing beams defined, a targeted resolution of 5° asks for six control bits. Obviously, the phase shifters and RF components are not ideal. This degrades the resulting beam accuracy.

Multiuser beamforming systems tries to control beams such that the maximum is pointing to the target but others users are in the nulled out region between side lobes to minimize crosstalk. Various calibrations are performed to deal with tolerances, errors and noise in the beamforming network. In addition, the system deploys a realtime monitoring to control the actual beamforming processing and to enable re-adjustment on the fly.

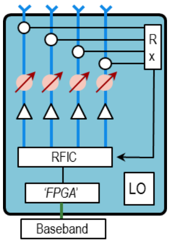

Fig. 8: Beamforming concept with realtime feedback control loop

One can build the beamforming network with concrete signal splitters, phase shifters and attenuators or amplifiers for level control. Moving forward with the integration of beamforming into 5G NR, the pressure on size reduction and price goes up. First integrated solutions are on the market with one main connection and support for four or more antenna elements with fully integrated analog beamforming. Based on the amount of RF power needed, beamforming ICs may include integrated amplifiers for lower power levels or use external amplifiers. It is a clear need that the form factor of these chipsets need to fit to the overall antenna design. As the signal routing from the beamforming IC to the RF antenna must be identical in length for each element, a 1:4 setup looks ideal as it can be placed just in the center of 4 neighboring antenna elements of the antenna back plane.

With the introduction of beamforming, the RF power level per path goes down significantly, so highly integrated and compact RF amplifiers can be deployed. The same effect is on the filters. Technologies like ceramic filters or printed filter structures will be more important in the future. This will enable new players in the market and may become a challenge for common filter vendors for base stations focusing on cavity filters up to now. Again, the amount of devices of filters and amplifiers will go up significantly as beamforming designs require many RF chains driving the phased array antenna elements.

Even so, space is at premium in hand held devices, the expectation is they will include some form of beamforming to help overcome the high free field attenuation at mmWave frequencies. The integration of beamforming antennas into mobiles will pose an even more challenging issue. Antennas need to be placed in positions where the hand does not cover them for mmWave frequencies. Another concern will be the power consumption and integration of modules and components enabling for active beam forming on a mobile device. Beam switching may become an alternative using an approach similar to Butler matrix designs.

Obviously, an up to now unknown level of integration will come and be required to enable the 5G designs in a small and cost efficient way.

TEST REQUIREMENTS

One can easily test discrete components like phase shifters or switches with vector network analyzers (VNA). Amplifier testing, integrated or standalone, can be accomplished using the same setup with a VNA.

It gets more demanding testing highly integrated beamforming chipsets with splitters, phase shifters and amplifiers with multiple antenna connections. True multiport network analyzers, which measure in parallel on many ports, are the tool of choice to characterize the IC on all ports. Only true parallel testing helps to identify any crosstalk within the chipset exercising and monitoring all interfaces simultaneously.

To optimize the performance of the beamforming system, all paths as shown in figure 8 need to be characterized and the data be stored for correction in the RFIC controlling the phase shifter and the level control elements. Phased array antenna structures have the elements very close together to save space. This creates another topic with crosstalk between the elements. For an optimal system design, this crosstalk is known and provided as calibration data to the RFIC. Again, an application for a true multiport vector network analyzer.

Fig. 9: Rohde & Schwarz R&S®ZNBT vector network analyzer with parallel testing on up to 24 ports up to 40 GHz

Due to the increase in signal bandwidth, customers request tests with real wideband signals, especially for ICs with integrated amplifiers. Rohde & Schwarz offers with the vector signal generator R&S®SMW200A and the signal and spectrum analyzer R&S®FSW a solution, which supports an unrivaled signal bandwidth of 2 GHz up to an RF frequency of 40 GHz without having to loop in external instruments to cover the high bandwidth.

Another topic due to the high level of integration will be the accessibility of measurement planes on modules or even chips. Some proposals include on the beamforming chipset even the RF antenna. To test the RF performance and characteristics of such a device or an integrated module with antenna, one needs to use over the air (OTA) testing. Rohde & Schwarz is the only test & measurement company offering far-reaching OTA solutions from antenna test software to different size shielded chambers including system level installations with RF test system and calibrated integrated antennas.

Fig. 10: Rohde & Schwarz mmWave OTA verification test system

SUMMARY

Beamforming is a common technology in the aerospace sector but with 5G NR pushing to integrate beamforming, the market is growing significantly. This drives companies to develop highly integrated ICs, which include a complete analog beamforming network. These ICs will complement digital beam forming elements in order to increase the number of antenna elements forming together a hybrid beamforming setup.

References:

1. Millimeter-Wave Beamforming: Antenna Array Design Choices & Characterization, M. Reil, G. Lloyd, White paper 1MA276, Rohde & Schwarz
2. Measurement of Beamforming Antenna in Transmit Mode, M. Reil, G. Lloyd, Application Note 1MA278, Rohde & Schwarz
3. Antenna Array Testing - Conducted and Over the Air: The Way to 5G, M. Kottkamp, C. Rowell, White Paper, 1MAA286, Rohde & Schwarz
4. Webinar Digital beamforming Techniques for Phased Array Systems, Peter Delos, Analog Devices
5. A Novel 28 GHz Beam Steering Array for 5G Mobile Device With Metallic Casing Application, Bin Yu , Kang Yang, Chow-Yen-Desmond Sim , and Guangli Yang
6. Low-Loss Compact Butler Matrix for a Microstrip Antenna, M. Bona, L. Manholm, J. P. Starski, Senior Member, IEEE, and B. Svensson, Member, IEEE